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Article

Functional response and predation rate of *Amblyseius swirskii* (Acari: Phytoseiidae) at three constant temperatures

Ferdows Rafizadeh Afshar and Malihe Latifi*

Department of Plant Protection, College of Agriculture, Vali-e-Asr University of Rafsanjan; Rafsanjan, Iran; E-mail: m.latifi@vru.ac.ir

* Corresponding author

ABSTRACT

Functional response and predation rate of *Amblyseius swirskii* (Athias-Henriot) on eggs of *Tetranychus urticae* Koch were determined on strawberry under laboratory conditions (70 ± 10% R.H. and 16L:8D h) and three constant temperatures of 25, 30 and 35°C. The type of functional response was affected by temperature. Type III functional response was determined for adult female of *A. swirskii* at 25°C, whereas type II was observed at 30 and 35°C. The longest handling time (T_h) (0.6 ± 0.005) was observed at 25°C and the shortest handling time (0.46 ± 0.003) and higher attack rate (a) (0.56 ± 0.054) were observed at 35°C. Handling time (T_h) decreased from 25 to 35°C. Temperature had a significant effect on the daily and total predation rates of each different stages: the predation rate increased from larva to adult and with temperature from 25 to 35°C, and the maximal value being reached at 35°C. The maximal predation capacity of female was about 40 eggs per day per females at 35°C. The results of this study showed the effect of temperature on functional response and predation rate of *A. swirskii*.

KEY WORDS: *Amblyseius swirskii*; biological control; predation rate; strawberry; *Tetranychus urticae*.

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INTRODUCTION

Among biological control agents, the predator species is selected in accordance with the type of target and the environmental conditions. Different parameters can modify the efficiency of biocontrol agents e.g. temperature (De Clercq *et al*. 2000; Mohaghegh *et al*. 2001), type of prey species, quality, size and appearance (Levin 1976; Hassell 1978; Stream 1994; Rasmy *et al*. 2002; Riahi *et al*. 2017), intraguild predation and competition, host distribution (Ali *et al*. 2011). Favorable plant traits for the predator constitute another relevant parameter for predation (Messina and Hanks 1998; Koveos and Broufas 2000).

Amblyseius swirskii Athias-Henriot is a predatory mite endemic to the Eastern Mediterranean region which is considered as an efficient biological control agent against thrips, whiteflies and phytophagous mites (Swirski *et al*. 1967; El-Laithy and Fouly 1992; Gerling *et al*. 2001; Nomikou *et al*. 2001, 2003).

Tetranychus urticae Koch is one of the harmful pests for crops and ornamental. It is a serious pest of strawberries in the field or greenhouse (Benuzzi *et al*. 1992; Easterbrook 1992). Owing to its high reproductive potential and short life cycle, this mite species is an important pest (Gorman *et al*.

2001). The chemical control of this pest is a major problem owing to its resistance to acaricides. Biological control by natural enemies is the main alternative to chemical control methods (Gorman *et al*. 2001).

Strawberry (*Fragaria x ananassa* Duchesne) is prone to the *Tetranychus* spp. and the intensity of attack depends on the strawberry varieties (Afifi *et al*. 2010).

Life table parameters, foraging behavior and multitrophic interactions are the main ways to evaluate predator's effectiveness. One of the important tools to evaluate foraging behavior of predator is functional response (Fathipour and Maleknia 2016).

This response is an important factor that tests the efficiency of a predator in managing a prey population and is a major component of the population modeling. It is useful for characterizing the ability of the predator in controlling the density of their prey (Murdoch and Oaten 1975; Berryman 1992). It describes the relationship between the numbers of preys killed at different prey densities (Rahman *et al*. 2012). This information may allow us to predict the ability of the agent to suppress *T. urticae* on strawberry. Among the environmental factors, the temperature has a very important role in the dynamics of predator-prey interactions. Several researches have shown that it affects on the predation rate and functional response (Thompson 1978; Perdikis *et al*. 1999; Mahdian *et al*. 2006; Zamani *et al*. 2006; Kouhjani *et al*. 2009; Yu *et al*. 2013). Consequently, the shape of the functional response is also affected by temperature, which is the intake rate of a predator as a function of the prey density (Holling 1959). This notion has been defined first for the vertebrates but it is used for the estimation of the efficiency of predatory mite on prey species (Everson 1980): the plateau levels in type I (linear increase with available preys), or type II (decelerating curve) and type III (a sigmoidal relationship) functional curves are described when there is a limitation of the intake even if the preys are available. Morever, the capacity of predation of a predator is one of the most important factors in biological control programs (Fan and Petitt 1994). This capacity is affected by several factors such as temperature, relative humidity, photoperiod, age of predator and presence of pollen (Fernando and Hassell 1980; Ganjisaffar *et al*. 2011; Jafari *et al*. 2012; Riahi *et al*. 2017; Fathipour *et al*. 2017).

In the present study, we examined the effect of three temperatures (25, 30 and 35°C) on voracity (daily and total prey consumption) and functional response of *A. swirskii* to *T. urticae* on strawberry leaves under laboratory conditions (70 ± 10% R.H. and 16L:8D h).

MATERIAL AND METHODS

Rearing of mites

The prey, *T. urticae,* was reared on strawberry (variety *camarus*) plants grown in 5 ml pots in greenhouse conditions (25 ± 1°C, 70 ± 10% R.H. and 16L:8D h). The strawberry leaves were put upside down on a wet sponge with a mixture of all stages of *T. urticae* inside Petri dish (9 cm diameter); which were used as rearing units for *A. swirskii*. The predatory mites fed by mixed stages of *T. urticae* ad libitum. Stock cultures were kept in growth chamber at 25 ± 1°C, 70 ± 10% R.H. and 16L:8D h. The experiments were conducted under controlled conditions 70 ± 10% R.H, 16L: 8D h photoperiod and three constant temperatures of 25 ± 1, 30 ± 1 and 35 ± 1°C.

Functional response experiment

Strawberry leaf discs (4.5 cm diameter) were placed upside down on a wet sponge inside a plastic Petri dish (6 cm diameter and 0.5 cm height). A strip of wet cotton around each leaf disc prevents the mites from scaping. Initial prey densities of 2, 4, 8, 16, 24, 32, 48 and 64 eggs of *T. urticae* were used for 25 ± 1°C and densities of 2, 4, 8, 16, 24, 32, 48, 64, 80, 128, 144, 160 and 200 eggs were used for 30 ± 1 and 35 ± 1°C. Low density treatments (2, 4, 8, 16, 24, 32, 48, 64) were replicated 15 and high density treatments (80, 128, 144, 160, 200) were replicated 10 times each.

During each test, different densities of eggs were obtained by placing different numbers of *T. urticae* females from the stock culture on leaf discs in the experimental units described above and allowed females to lay eggs for 24 h. After this period females were removed from each leaf disc, the right number of eggs adjusted by removing extra eggs. The functional response experiments were conducted with 24 h starved, 3-day old females. Each experiment was carried on with a single starved female in per experimental unit without prey replenishment. After 24 h, the females were removed and the predation estimated in terms of number of eggs attacked per female.

Statistical analysis of functional response

To determine the shape of functional response, we used a logistic regression of the proportion of prey killed as a function of initial density.

$$N_e / N_0 = \frac{\exp(P_0 + P_1 N_0 + P_2 N_0^2 + P_3 N_0^3)}{1 + \exp(P_0 + P_1 N_0 + P_2 N_0^2 + P_3 N_0^3)}$$

Where -N_e is the number of prey consumed,
- N_0 is the initial prey density,
- (Ne/N_0) is the probability of prey consumption,
- P_0, P_1, P_2 and P_3 are the maximum likelihood estimates of the intercept, linear, quadratic and cubic coefficients, respectively.

These parameters can be estimated by using the CATMOD procedure using SAS program (Juliano 2001). Negative or positive reactive linear coefficient in the expression fit to data on proportion killed N_e/N_0 versus initial number of prey N_0, indicate a type II or type III functional response, respectively. A non-linear least squares regression of number of prey killed versus initial number of prey was used to estimate and compare parameters of functional responses using the NLIN procedure in SAS. Functional response data were fitted to the random predator equation (Juliano 2001). This equation takes into account for prey depletion without replacement of prey during the experiment (Rogers 1972). The following equation used for type II functional responses:

$$N_e = N_0\{1 - \exp[a(T_h N_e - T)]\}$$

- a is the attack rate
- T_h is the handling time
- T is the total time available for predator

For type III functional responses, where a is a function of initial prey density, the following equation used:

$$N_e = N_0\left\{1 - \exp\left[\frac{(d + bN_0)(T_h N_e - T)}{(1 + cN_0)}\right]\right\}$$

where b, c and d are constants.

Predation rate experiment

The experimental units were similar to the functional response experiment. In order to determine the predation rate of *A. swirskii*, a newly emerged larva of the predator, was introduced to each experimental unit. According to preliminary data, each experimental unit contained 25, 30, 35, 45 and 90 eggs of *T. urticae* for larva, first nymph and second nymph, male and female of the predator respectively, as food. The number of eggs consumed by the predator was recorded after 24

h. Observations on the developmental stage of *A. swirskii* were done twice a day. Consumption of eggs of *T. urticae* by *A. swirskii* was studied throughout the life cycle. After the last molting, the males were supplied with new females for mating. To separate the predation rate of males from that of females, the consumption rate of 12 single-males (in each temperature) was recorded. To determine the female consumption rate, the average male consumption was subtracted from the consumption of pairs. Each treatment was replicated 40 times.

Statistical analysis of predation rate

Daily and total predation rate of different stages of *A. swirskii* at three temperatures (25, 30 and 35°C) were investigated in a factorial experiment arranged in the CRD (Completely Randomized Design). Data were analyzed using two way analysis of variance (ANOVA). Differences among the means were compared using HSD (Honestly Significant Difference) test.

RESULTS

Functional response

The functional response and estimated parameters are affected by different factors e.g. the host plant, the temperature, the type of prey or host and prey stages (Wang and Ferro 1998; De Clercq *et al*. 2000; Mohaghegh *et al*. 2001).

In our results the type of functional response changed as the temperature increased (Table 1). At 30 and 35°C, the logistic regression analysis showed that the response was a type II, i.e., the linear coefficient (P_1) is < 0 (Table 1). In this type of functional response, the decelerating intake rate is measured by the decreasing proportion of prey killed per predator as a function of the prey density increase. At 25°C, the logistic regression analysis showed that the response was a type III, i.e., the linear coefficient (P_1) is > 0 (Table 1).

Table 1. Predation by *Amblyseius swirskii* female: Maximum likelihood estimation by logistic regression (prey eaten % function of initial prey densities/female).

Temperature	Parameters	Estimate	SE	χ^2	*P*
25	Intercept (P_0)	−1.075	0.25	17.75	< 0.0001
	Linear (P_1)	0.3187	0.03	103.58	< 0 .0001
	Quadratic (P_2)	− 0.0089	0.00099	81.81	< 0.0001
	Cubic (P_3)	0.000068	8.94E−06	57.71	< 0.0001
30	Intercept (P_0)	2.16	0.159	184.65	< 0.0001
	Linear (P_1)	− 0.0109	0.0054	4.11	0.0426
	Quadratic (P_2)	− 0.00017	0.000051	10.36	0.0001
	Cubic (P_3)	6.88E−07	1.45E−07	22.54	< 0.0001
35	Intercept (P_0)	2.53	0.176	205.83	< 0.0001
	Linear (P_1)	− 0.0153	0.00584	6.83	0.009
	Quadratic (P_2)	− 0.00014	0.000055	6.64	0.01
	Cubic (P_3)	6.35E−07	1.52E−07	17.3661	< 0.0001

The curves of the functional response at 25, 30 and 35°C were given in Figure 1. The handling time and attack rate affect the shape of the functional response and the functional response curves can be discriminated by evaluating these parameters. The attack rate at 30 and 35°C were 0.433 ± 0.039 h^{-1} and 0.56 ± 0.054 h^{-1}, respectively. The handling time at 30 and 35°C were 0.48 ± 0.004 h and 0.046 ± 0.003 h respectively (Table 2).

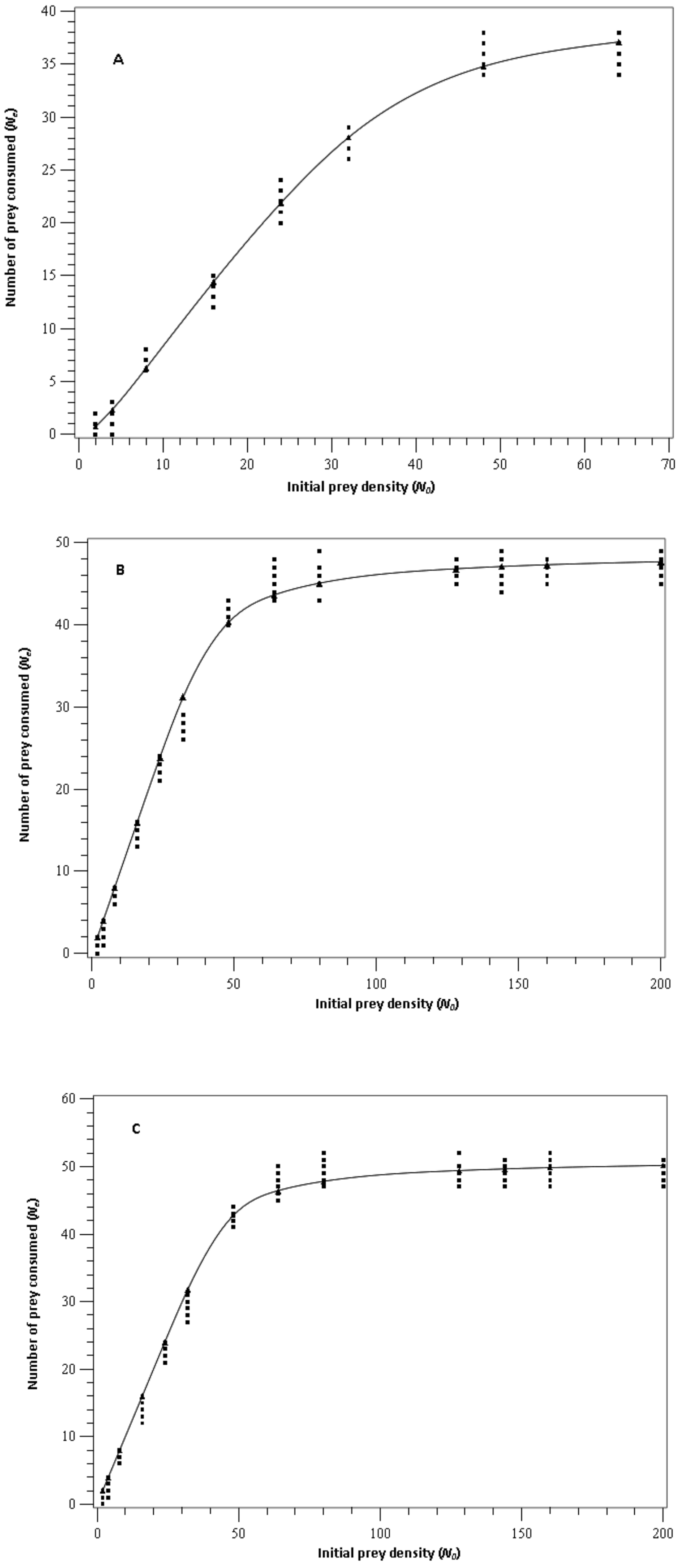

Figure 1. Functional response of *Amblyseius swirskii* to eggs of *Tetranychus urticae* at 25 (A), 30 (B) and 35°C (C).

The parameters b and T_h at 25°C were 0.0094 ± 0.0004 and 0.6 ± 0.005 h (Table 2). Our results revealed that temperature affected the attack rate and handling time of *A. swirskii*. The longest handling time observed at 25°C and the shortest one was at 35°C. The attack rate was higher at 35 than 30°C. The handling time decreased as the temperature increased from 25 to 35°C. This indicates that the predator response differs in terms of handling time and attack rate at three different temperatures.

Table 2. Parameters (mean ± SE) estimated by random predator equation, indicating functional response of *Amblyseius swirskii* females to densities of *Tetranychus urticae* egg at three constant temperatures.

Temperature (°C)	Type	a (h^{-1})	T_h (h)	b
25	III	[a] ____	0.6 ± 0.005	0.0094 ± 0.0004
30	II	0.433 ± 0.039	0.48 ± 0.004	____
35	II	0.56 ± 0.054	0.46 ± 0.003	____

[a] In the best fit type III model, relationship between attack rate and initial number of prey is linear ($a = bN_0$).

Predation rate

Our results showed that:

(i) The mean daily (ANOVA, df = 5,494; F = 1749.433; $p < 0.05$) (Table 3) and the total predation rate (ANOVA, df = 5,493; F = 16409.938; $p < 0.05$) (Table 3) were found significantly different between the immature stages and female and male at three constant temperatures (Table 4).

Table 3. Two-way analysis of variance (ANOVA) of the effect of temperature and predator stage on daily and total predation rate of *Amblyseius swirskii* to eggs of *Tetranychus urticae* on strawberry.

Source	df	Mean square	F	*P*
Daily predation rate				
Temperature	2	4740.808	1222.905	0
Predator stage	5	6781.985	1749.433	0
temperature-predator stage	10	92.218	23.788	0
Total predation rate				
Temperature	2	408830.4	422.807	0
Predator stage	5	15867473	16409.94	0
temperature-predator stage	10	93870.42	97.08	0

(ii) The temperature has a pronounced effect on the predation rate of *A. swirskii, i.e.* the daily predation (df = 2,494; F = 1222.905; $p < 0.05$) and the total predation (df = 2, 494; F = 422.807; $p < 0.05$) (Table 3). This effect with temperature was observed for each stage. Consecutively, the daily and total predation rates of *A. swirskii* larvae, protonymph, deutonymph and female feeding on eggs of *T. urticae* increased significantly (Table 4).

(iii) There was a significant interaction between temperature and predator stage in both daily (df = 10,494; F = 23.788; $p < 0.05$) and total (df = 10,494; F = 97.08; $p < 0.05$) predation rate (Table 3).

(iv) The differences between total predation rates of male at 25, 30, 35°C were significant with exception of the daily predation by males at 30 and 35°C (Table 4). The daily predation rates of larva, deutonymph, female and male of the predator were significantly different at each tested temperature (Table 4).

(v) As a rule, for each developmental stage, and at each temperature, the total and the daily predation rate of the different stages of *A. swirskii*, increased from the larva to the adult, and increased from 25 to 35°C (Table 4). Even if at each temperature, there is no difference between the total predation rate of (larva and protonymph) and (protonymph and deutonymph), the total predation rate on immature, male and female were significantly different (Table 4). The daily and total predation rate of the males and females were higher than that of immature stages and these rates increased from 25 to 35°C. The maximal predation on eggs of two-spotted spider mite was registered by the females at 35°C (Table 4).

Table 4. Daily and total predation rate of *Amblyseius swirskii* to eggs of *Tetranychus urticae* on strawberry at three constant temperatures

	Daily predation rate			Total predation rate		
Predator stage	25°C	30°C	35°C	25°C	30°C	35°C
Larva	4.1 ± 0.12^{aA} (40)	6.02 ± 0.15^{bA} (38)	13.87 ± 0.16^{cA} (38)	4.1 ± 0.12^{aA} (40)	6.02 ± 0.15^{bA} (38)	13.87 ± 0.18^{cA} (38)
Protonymph	9.65 ± 0.15^{aB} (39)	14.89 ± 0.18^{bB} (36)	19.94 ± 0.16^{cB} (35)	11.08 ± 0.54^{aAB} (39)	14.89 ± 0.18^{bAB} (36)	19.94 ± 0.16^{cAB} (35)
Deutonymph	15.26 ± 0.44^{aC} (33)	21.14 ± 0.23^{bC} (31)	24.85 ± 0.26^{cC} (32)	23.27 ± 1.43^{aB} (33)	36.19 ± 1.8^{bBC} (31)	42.16 ± 2.20^{cB} (32)
Immature stages	10.37 ± 0.22^{aB} (33)	15.31 ± 0.17^{bB} (31)	20.54 ± 0.19^{cB} (32)	38 ± 1.61^{aC} (33)	57.1 ± 1.71^{bC} (31)	76.1 ± 2.18^{cC} (32)
Female	25.72 ± 0.12^{aD} (19)	36.65 ± 0.3^{bD} (18)	40.05 ± 0.22^{cD} (20)	1008.58 ± 13.33^{aD} (19)	1223.17 ± 25.23^{bD} (18)	1295.3 ± 19.81^{cD} (20)
Male	20.93 ± 0.51^{aE} (11)	33.82 ± 2.76^{bE} (13)	35.57 ± 0.09^{bE} (12)	645.1 ± 9.66^{aE} (11)	820.1 ± 11.4^{bE} (13)	913 ± 12.46^{cE} (12)

Means followed by different small letters in a row and by different capital letters within a column are significantly different ($p < 0.05$). Numbers in parentheses show the number of replicates in each treatment.

DISCUSSION

The results suggest that the temperature affects the functional response and the predation rate of *A. swirskii*. The predation by *A. swirskii* on eggs of *T. urticae* followed a type III functional response at 25°C, and a type II functional response at 30 and 35°C. These types of functional responses are common among arthropod predators (Hassell *et al.* 1977).

The behavior of females of *A. swirskii* confirms that a single invertebrate predator species may exhibit different responses depending on the type of host plant (Messina and Hanks 1998; Koveos and Broufas 2000), temperature (De Clercq *et al.* 2000; Mohaghegh *et al.* 2001), age of predator (Ding-Xu *et al.* 2007; Fathipour *et al.* 2017), type of prey species, size and appearance (Hassell 1978; Stream 1994) and insecticides (Poletti *et al.* 2007).

The mean number of killed preys is used to determine the daily needs of predators. The efficiency of this species was affected first by the temperature, with a maximal intensity at 30°C, and by the percentage of adults in the population and of females due to the reproduction, the gravid females require a larger nutritional requirement than the immature males (Nguyen and Shih 2011).

Type II functional response is the most common response of the phytoseiids to an increasing density of spider mites (Sabelis 1985; Skirvin and Fenlon 2003; Osman and Tawfik 2010). The attack rate and the handling time are the two main factors which change in the functional response. These factors measure the effectiveness of the predation and change with the temperature (Holling 1959; Hassell and Waage 1984). Since biochemical processes in ectotherms are significantly affected by temperature, the handling time and attack rate are directly related to ambient temperature. The attack rate (a) by *A. swirskii* increased 33% at 35°C vs. 30°C (Table 2). The handling time (T_h) showed a reverse tendency: at 30°C, T_h = 10 times the value estimated at 35°C (Table 2).

At 25°C, the functional response is a type III: the linear coefficient is low (0.0009) but positive.

Therefore, the number of killed preys increased with prey density linearly up to an inflection point. The relationship of attack rate (a) to initial prey density N_0 was linear with a slope (b) of 0.009.

Our results differed from the experiments on green bean leaves and 14L:10D by Xiao *et al.* (2013). They reported that *A. swirskii* exhibited the type II functional response when feeding on the eggs of *T. urticae* at 26°C, whereas we had a type III response at 25°C (Table 5). Fathipour *et al.* (2017) reported that 6-day old female of *A. swirskii* showed type III functional response but 11, 16 and 21 day old females showed type II functional response to eggs of *T. urticae* on cucumber leaf disc at 25°C (Table 5). The difference is attributed to the condition of the experimental conditions and the age of predator. The functional response of a phytoseiid mite may be affected by the size of the experimental unit and by the plant species (Akpokodje *et al.* 1990; Shipp and Whitfield 1991; Skirvin and Fenlon 2001). Midthassel *et al.* (2015) reported that *A. swirskii* fed on eggs of *Suidasia medanensis* (syn.: *S.* pontifica) exhibited a type II functional response at 25°C (Table 5). Although predators that exhibit type II functional response have been successfully released as biological control agents, but predators that exhibit type III are considered as efficient biological control agents (Xiao and Fadamiro 2010)

The comparison of *A. swirskii* functional response with other predatory species:

1) *Amblyseius longispinosus* (Evans) fed on *Schizotetranychus nanjingensis* Ma & Yuan: at six temperatures, the tendencies of handling time (T_h) and successful attack rate (a) are similar to that of our experiments (Zhang *et al.* 1999) (Table 5).

2) *Typhlodromus kettanehi* Dosse: Females showed type II functional response to different densities of eggs, larvae, adult males and females of *T. urticae* (Shirdel *et al.* 2004) (Table 5).

3) *Iphiseius degenerans* (Berlese), exhibited a type III functional response feeding on eggs of *T. urticae* on bean leaf discs (Vantornhout 2006) (Table 5).

4) *Phytoseius plumifer* (Canestrini & Fanzago): Females of *P. plumifer* fed on nymphal stages of *T. urticae* showed type II functional response from 15–30°C (Kouhjani Gorji *et al.* 2009). The maximum attack rate (a) (0.073) was observed at 30°C and the minimum handling time (T_h) (0.55) was observed at 35°C (Table 5).

5) *Neoseiulus barkeri* (Hughes) showed a type II functional response at four constant temperatures (20, 25, 30 and 35°C) on nymphal stages of *T. urticae* (Jafari *et al.* 2012) (Table 5). They also reported that the temperature had a significant effect on the prey consumption of adult females of *N. barkeri*. The minimum and maximum daily prey consumption rates of the entire immature stages of *N. barkeri* at six constant temperatures (15, 20, 25, 27 30 and 35°C) were observed at 15 and 35°C respectively, and the consumption rates increased with increasing temperature.

6) *Phytoseiulus persimilis* Athias-Henriot: At constant temperatures, on different life stages of *T. urticae* showed a type II functional response from 20 to 35°C (Fazlul Hoque *et al.* 2010) (Table 5). They showed that handling time generally decreased with the increase in temperature, whereas successful attack rate increased with temperature except at 30°C. This predator also showed type II functional response on adult of *T. urticae* (Seiedy *et al.* 2012) (Table 5)

7) *P. persimilis* and *T. bagdasarjani* Wainstein & Arutunjan: 3-days old mated females of these two predators fed on different densities of eggs of *T. urticae* on rose plant, showed type III functional response (Moghadasi *et al.* 2013) (Table 5). For *P. persimilis*, handling time was lower and attack rate was higher than our results whereas for *T. bagdasarjani*, handling time and attack rate were lower than our results. There is substantial difference between experimental conditions such as host plant and predator species.

8) *Typhlodromus negevi* Swirski & Amitai: Females of *T. negevi* fed on nymphal stages of *T. urticae* showed type II functional response at 25°C (Rasmy *et al.* 2014). The attack rate (a) and handling time (T_h) of females were 0.1068 and 1.0796 (Table 5). The lower value of attack rate (a) is attributed to the size of the available preys (eggs vs. nymphs).

Table 5. Variation of handling time and attack rate of *Amblyseius swirskii* and comparison with other predators.

	Species	Preys	Experimental conditions			Results		
			Photoperiod	Temperatures (°C)	Vegetal support	Functional response	Handling time (T_h)	Attack rate (a)
1	*Amblyseius swirskii*	Eggs *Suidasia medanensis*	16L:8D	25	French bean plant	Type II	0.027	3.84
2	*A. swirskii*	Eggs *T. urticae*	14L:10D	26	Green bean plant	Type II	0.52	0.42
3	*A. swirskii*	Egg *T. urticae*	16L:8D	25	Cucumber	Type III (6-day old female) Type II (11, 16, 21-day old female)	0.66 (6 day) 0.42 (11 day) 0.84 (16 day) 0.97 (21 day)	0.0027 (6-day) 0.08 (11-day) 0.11 (16-day) 0.072 (21-day)
4	*A. longispinosus*	Female *Sc. nanjingensis*	---	10–35	Bamboo plant	Type II	0.48 (10) 0.14 (15) 0.12 (20) 0.14 (25) 0.084 (30) 0.085 (35)	0.54 (10) 0.35 (15) 1.08 (20) 1.63 (25) 1.46 (30) 1.54 (35)
5	*Euseius hibisci*	Egg *T. urticae*	12L:12D	25	Strawberry	Type II	0.101	0.813
6	*Typhlodromus kettanehi*	Larvae and females *T. urticae*	14L: 10D	24	Mulberry	Type II	0.3 (larvae) 2.67 (females)	0.0466 (larvae) 0.0188 (females)
7	*Iphiseius degenerans*	Egg *T. urticae*	16L:8D	25	Bean plant	Type III	1.27E−08	0.00012
8	*Phytoseius plumifer*	Nymphal stages of *T. urticae*	16L:8D	15-30	Fig	Type II	0.492 (15) 0.506 (20) 0.651 (25) 0.425 (30)	0.027 (15) 0.037 (20) 0.059 (25) 0.03 (30)
9	*Phytoseiulus persimilis*	Different life stages *T. urticae*	---	20-35	Bean plant	Type II	3.11 (20) 2.91 (25) 3.03 (30) 2.56 (35)	0.004 (20) 0.005 (25) 0.009 (30) 0.008 (35)
10	*N. californicus*	Egg *T. urticae*	16L:8D	25	Cucumber	Type II	1.6451	0.0936
11	*T. bagdasarjani*	Egg *T. urticae*	16L:8D	25	Cucumber	Type II	1.8013	0.0893
12	*Neoseiulus barkeri*	Nymphal stages *T. urticae*	12L:12D	20-35	Cucumber	Type II	0.92 (20) 0.82 (25) 0.6 (30) 0.55 (35)	0.036 (20) 0.064 (25) 0.073 (30) 0.064 (35)
13	*Phytoseiulus persimilis*	Adult *T. urticae*	16L:8D	25	Cucumber	Type II	3.5143	0.1142
14	*Phytoseiulus persimilis*	Egg *T. urticae*	16L:8D	25	Rose	Type III	0.5939	0.0187
15	*T. bagdasarjani*	Egg *T. urticae*	16L:8D	25	Rose	Type III	0.2409	0.0033
16	*Typhlodromus negevi*	nymphal stages *T. urticae*	-	25	Castor plant	Type II	1.08	0.11
17	*Neoseiulus californicus*	Eggs *T. urticae*	16L:8D	25	Bean plan	Type II	2.0213	0.1721
18	*N. longispinosus*	Eggs *T. urticae*	16L:8D	25	Bean plan	Type II	1.3020	0.1196
19	*A. swirskii*	Egg *T. urticae*	16L:8D	25–35	Strawberry	Type III (25) Type II (30 & 35)	0.6 (25) 0.48 (30) 0.46 (35)	0.0094 (25) 0.43 (30) 0.56 (35)

References: 1: Midthassel *et al*. (2015); 2: Xiao *et al*. (2013); 3: Fathipour *et al*. (2017); 4: Zhang *et al*. (1999); 5: Badii *et al*. (2004); 6: Shirdel *et al*. (2004); 7: Vantornhout (2006); 8: Kouhjani Gorji *et al*. (2009); 9: Fazlul Hoque *et al*. (2010); 10 & 11: Farazmand *et al*. (2012); 12: Jafari *et al*. (2012); 13: Seiedy *et al*. (2012); 14 and 15: Moghadasi *et al*. (2013); 16: Rasmy *et al*. (2014); 17 & 18: Song *et al*. (2016); 19: Present study.

There are some other predators that showed type II functional response to eggs of *T. urticae* such as *Euseius hibisci* (Chant) (Badii *et al*. 2004), *Neoseiulus californicus* (McGregor) and *N. longispinosus* (Evans) (Song *et al*. 2016), and *N. californicus* and *T. bagdasarjani* (Farazmand *et al*. 2012) (Table 5).

The high predation rate at 35°C, makes *A. swirskii* a promising candidate for controlling *T. urticae* infestations at temperatures > 25° and provide fast suppression of *T. urticae* infestations by limiting the birth rate of this pest; clearly, females and males should make up a large proportion of the released predator.

Kouhjani *et al*. (2009) showed that daily consumption rate of *P. plumifer* nymphal stages (protonymph and deutonymph) to *T. urtice* nymphal stages on fig leaf disc, increased as the temperature increased, but total prey consumption decreased as temperature increased. Daily consumption rate of female increased with temperature from 15 to 35°C; total predation rate of female increased from 15 to 25°C, decreased at 30°C then increased again at 35°C. They showed that the highest total prey consumption was at 25°C. Ganjisaffar *et al*. (2011) reported that daily prey consumption of *T. bagdasarjani* nymphal stages to *T. urticae* nymphal stages, increased with increasing temperature from 15 to 25°C, decreased at 30°C and again increased at 35°C. Their results showed that temperature affects on prey consumption of predators. The difference was due to different predator species, different host plant and different life stages of the prey. Some other factors, such as type of experimental arena, photoperiod and humidity can also affect on feeding of predator (Fernando and Hassell 1980).

Our results also showed that daily and total predation rate can affected by age of predator and increased from larvae to adults; the highest values were observed in female adults.

Moreover, in two other studies, they showed that consumption rate of different stages of *T. bagdasarjani* (Khanamani *et al*. 2014) and *A. swirskii* (Riahi *et al*. 2017), on immature stages of *T. urticae*, increased by increasing the age of predator, and the highest predation rate observed in female stage. These results are similar to our finding. The estimated predation rate of different stages of *A. swirskii* in this study at 25°C were more than that reported in these two studies, due to difference in stages of *T. urticae* that used as prey, host plant and predator species (egg plant in Khanamani's study). Other researches also showed the effect of age on prey consumption of predator (Sabelis 1985; Sengonca *et al*. 2003; Ding-Xu *et al*. 2007; Alipour *et al*. 2016; Fathipour *et al*. 2017).

Amblyseius swirskii is a polyphagous mite and is not specialized on a specific type of prey: under controlled conditions, a single type of prey is supposed to be insufficient and the nutritional deficit may be compensated by higher consumption of the available preys (Greenstone 1979). Functional response and predation rate, though important tools, cannot determine success or failures of a biological control agent, alone. Intrinsic growth rates, host patchiness, prey preference, competition, host plant traits and environmental factors (abiotic and biotic) have important influence on the efficiency of predator in managing the prey population (Omkar Pervez 2005). However, although these controlled laboratory studies provide some insight into the predator-prey interactions, a more conclusive estimation of biocontrol potential requires more studies under more realistic conditions before the development of ideal management tactics for the control of *T. urticae* at Temperatures > 30°C.

According to our results, *A. swirskii* appears to be a promising candidate as a biological control agent when the temperature is above 30°C on strawberry culture. This species is less influenced by temperature. The two coefficients "Handling time" and "Attack rate" are likely to be favorable for predicting the efficiency of different species according to the nature of the pests and climatic conditions: each species performs differently according to these parameters. Various parameters of different predator species may help significantly in the final selection of the species, crossing the three parameters: temperature, nature of the culture, and pest species.

Our results suggest that predator-dependent functional responses, including the forms based on interference that we consider here, should be more widely studied in the literature. Because some predator-dependent models of the functional response predict asymptotic feeding rates at high prey abundance that are independent of predator abundance, but others predict asymptotes that depend on predator abundance (Skalski and Gilliam 2001).

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واکنش تابعی و میزان شکارگری *Amblyseius swirskii* (Acari: Phytoseiidae) در سه دمای ثابت

فردوس رفیع‌زاده افشار و ملیحه لطیفی[*]

گروه گیاهپزشکی، دانشکده کشاورزی، دانشگاه ولی عصر (عج) رفسنجان، رفسنجان، ایران؛ رایانامه: *m.latifi@vru.ac.ir*

[*] نویسنده مسئول

چکیده

واکنش تابعی و میزان شکارگری کنه شکارگر *Amblyseius swirskii* روی تخم کنه *Tetranychus urticae* در شرایط آزمایشگاهی (رطوبت نسبی ۷۰±۱۰ درصد، دوره نوری ۱۶ ساعت روشنایی به ۸ ساعت تاریکی) و سه دمای ثابت ۲۵، ۳۰ و ۳۵ درجه سلسیوس، روی گیاه توت فرنگی تعیین شد. نوع واکنش تابعی تحت تاثیر دما قرار گرفت. برای کنه ماده *A. swirskii* در دمای ۲۵ درجه سلسیوس نوع سوم واکنش تابعی مشخص شد، در حالی‌که در دماهای ۳۰ و ۳۵ درجه سلسیوس نوع دوم مشاهده شد. بیشترین زمان دستیابی (T_h) (۰/۶±۰/۰۰۵) در دمای ۲۵ و کمترین زمان دستیابی (۰/۴۶ ± ۰/۰۰۳) و بیشترین میزان حمله (a) (۰/۵۶ ±۰/۰۵۴) در دمای ۳۵ درجه سلسیوس مشاهده شد. زمان دستیابی از دمای ۲۵ به دمای ۳۵ درجه سلسیوس کاهش یافت. دما اثر معنی‌داری روی میزان شکارگری کل و روزانه مراحل مختلف داشت. میزان شکارگری از مرحله لاروی به مرحله بالغ و از دمای ۲۵ به دمای ۳۵ درجه سلسیوس افزایش یافت و در دمای ۳۵ درجه سلسیوس به بیشترین مقدار رسید. بیشترین ظرفیت شکارگری ماده در حدود ۴۰ تخم در روز در دمای ۳۵ درجه سلسیوس بود. نتایج این پژوهش نشان دهنده تأثیر دما بر واکنش تابعی و میزان شکارگری *A. swirskii* است.

واژگان کلیدی: *Amblyseius swirskii* ؛ کنترل بیولوژیک؛ میزان شکارگری؛ توت‌فرنگی؛ *Tetranychus urticae*.

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